Development of EUV Chemically Amplified Resist

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Contents

Requirement for EUV resist

ITRS 2013 Edition, Lithography, p7-10

Resolution (ITRS2013)

- ✓ LS (Minimum production half pitch/ Production year)

  13nm hp @2017, **12nm hp** @2018 (MPU fin and flash memory)

LWR (ITRS2013)

- ✓ **1.7nm** @2017, **1.5nm** @2018

Through put (SPIE2016 from ASML)

- ✓ 75 wafer / hr @2015, 125 wafer / hr @ 2016 (plan)

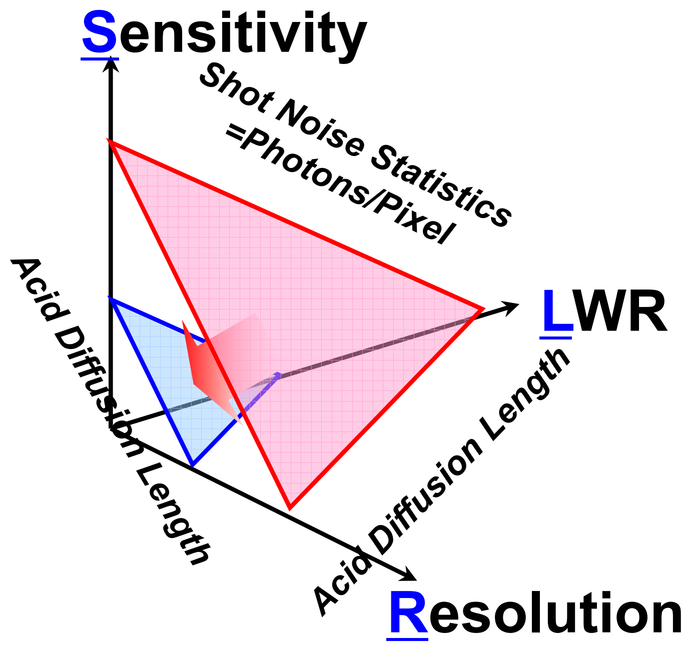
  DTS = 20mJ/cm^2 is required to achieve target through put

- **Improvement of ultimate resolution, LWR and sensitivity is required at the same time**

Development Status for EUV Resist

D.Van Steenwinckel et al., Proc. SPIE, 5753, 269-280 (2005)

- RLS trade-off



- To overcome RLS trade-off ･･･

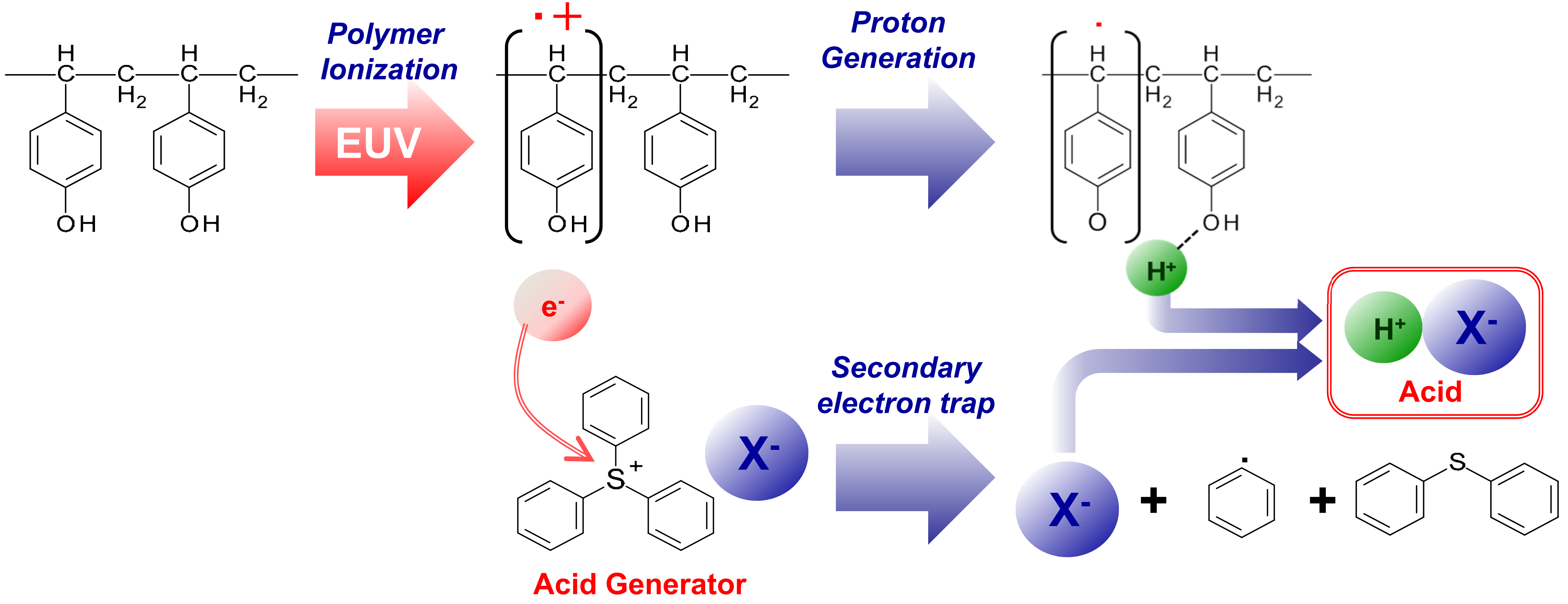
1. Enhancement of acid generation efficiency, de-protecting efficiency and dissolution rate in exposed area
2. Suppression of acid diffusion and dissolution rate in unexposed area

These items need to improve at the same time

Acid Generation Mechanism

T. Kozawa et al. J. Vac. Sci. Technol. B, Vol.*24*, No. 6, L27 (2006)

- Model of Acid Generation with EUV exposure



- For enhancement of acid generation efficiency ･･･
  - ✓ Increase proton source
  - ✓ Increase reactivity of PAG cation with electron

TOK Resist Formulation for Positive Tone

Resist A (Control)

DTS:	**38.6mJ/cm^2**
LWR:	**6.2nm**
Resolution:	**14nm hp**

- To improve EUV lithographic performance ･･･

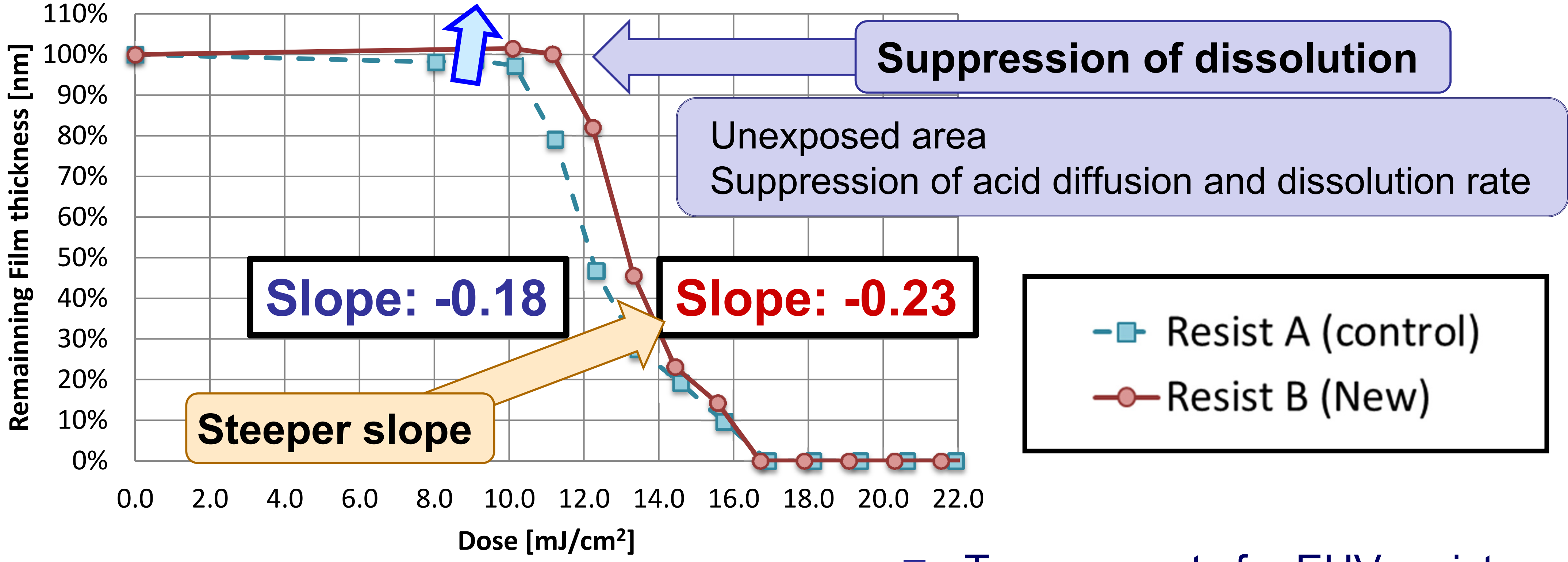
Resist B (New)

- Exposed area
  - ✓ Improvement of acid generation efficiency
    - ●Applying of high quantum yield PAG cation
    - ●Increasing of proton source

- Unexposed area
  - ✓ Suppression of acid diffusion
    - ●Increasing of Tg enhancer

EUV Contrast Curve
Resist A, B

- EUV contrast curves of resist A and B



Suppression of dissolution

Unexposed area
Suppression of acid diffusion and dissolution rate

Slope: -0.18

Slope: -0.23

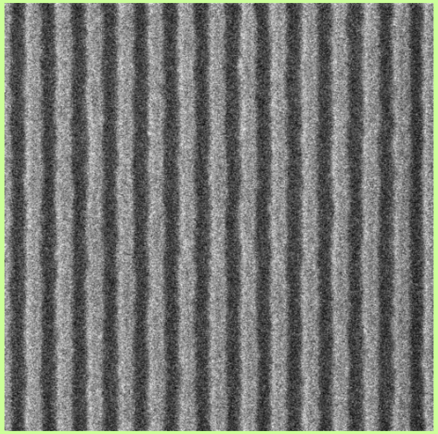
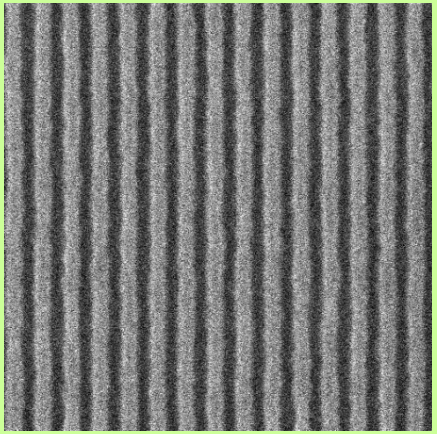
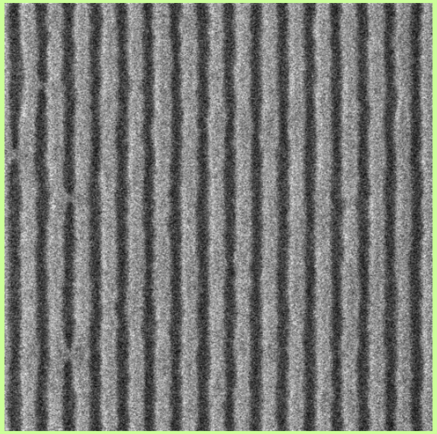
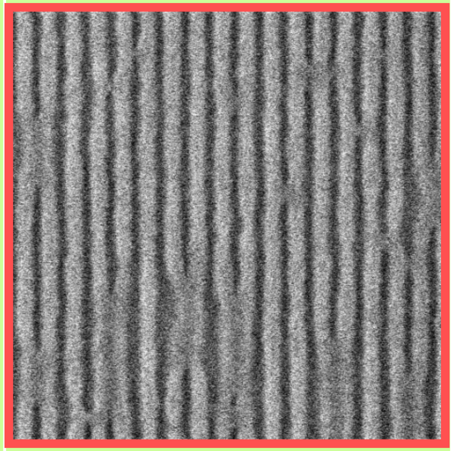
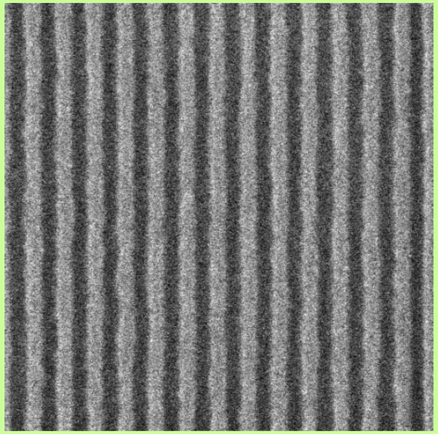
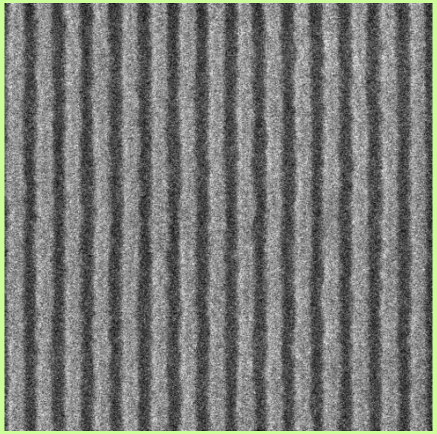
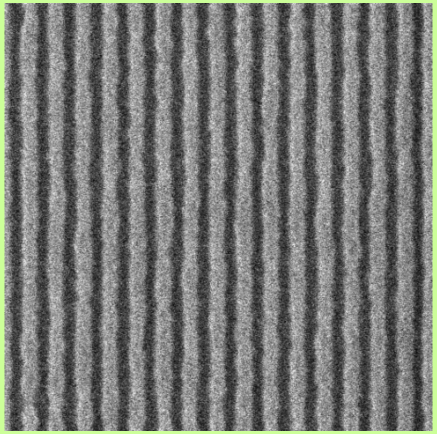
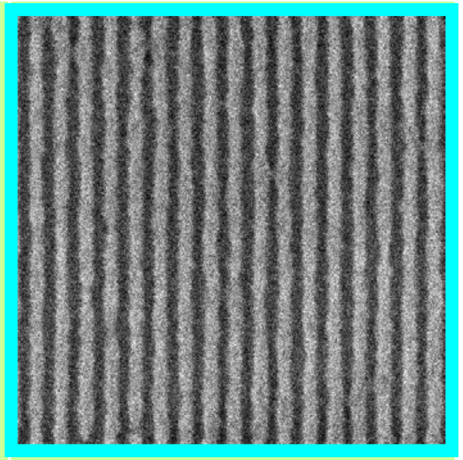
Steeper slope

Exposed area
Enhancement of acid generation efficiency, de-protection efficiency and dissolution rate

- Two concepts for EUV resist development was confirmed resist B

NXE3300 Result
Ultimate Resolution

Substrate: Organic UL 20nm
Resist FT: 25nm
Illumination: NA 0.33, dipole X45 0.848/0.307
Reticle: Supper NOVA2 metal
Development: TMAH2.38% LD-30s

Sample	16nm hp	15nm hp	14nm hp	13nm hp
Resist A **(Control)** DTS:38.6mJ/cm^2 @14nm hp LWR: 6.2nm Z-factor: 2.04E-08				
Resist B **(New)** DTS:43.0mJ/cm^2 @14nm hp LWR: 5.8nm Z-factor: 1.59E-08				

Line CD 11.8nm

- Resist B resolved 13nm hp LS pattern

*Z-factor (mJ*nm3)*
= (Resolution)^3 x (LER)^2 x Sensitivity

T. Wallow et al., Proc. SPIE, 6921, 69211F (2008)

For Faster Sensitivity and Lower LWR

Resist B

	16nm hp	14nm hp	13nm hp
DTS:	49.8mJ/cm^2	43.0mJ/cm^2	41.3mJ/cm^2
LWR:	6.4nm	5.8nm	6.3nm

- To improve sensitivity and LWR ･･･

Resist C

- Exposed area
  - ✓ Improvement of acid generation efficiency
    - Increasing of PAG amount
  - ✓ Improvement de-protecting efficiency
    - Increasing of protecting group
- Unexposed area
  - ✓ Suppression of acid diffusion
    - Changing Tg enhancer from resist B

NXE3300 Result
Resist C: Faster Sensitivity & Lower LWR

Substrate SOC/SOG 75nm/10nm,
Resist F.T.:30nm
Illumination: NA 0.33, SMO setting close to a manufacturable condition for N5 generation L/S(not Dipole)
Development: TMAH 2.38% LD-30s

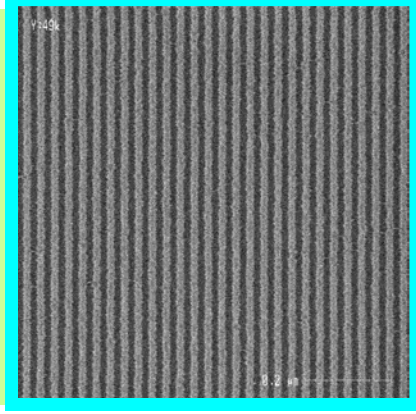
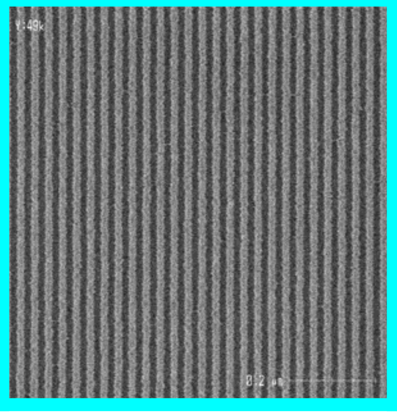
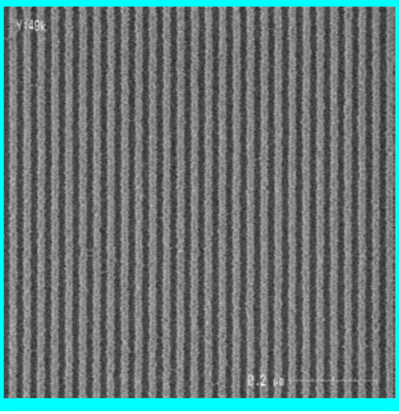
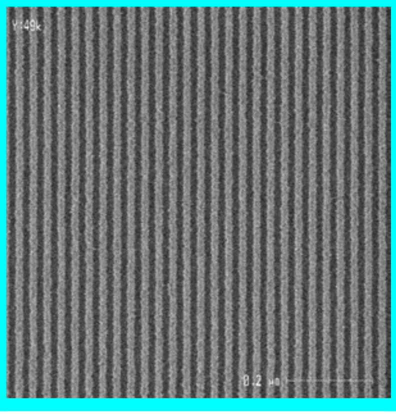
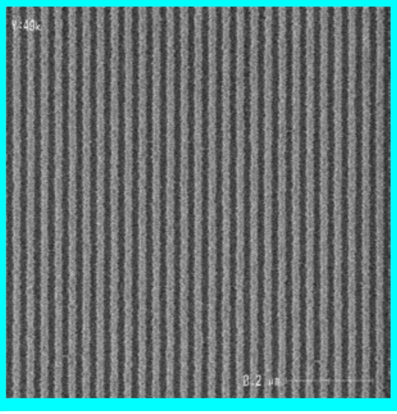
Resist B
16nm hp

DTS: 49.8mJ/cm^2
LWR: 6.4nm
Z-factor: 2.82E-08

Resist C
16nm hp

DTS: 24.0mJ/cm^2
LWR: 5.4nm
Z-factor: 1.06E-08

Resolved

Focus	-0.050um	-0.025um	Center	+0.025um	+0.050um
Resist C					

- Resist C showed faster sensitivity and lower LWR with wide DOF (>0.1µm)

TOK Resist Formulation for Negative Tone with TMAH

- **Why study EUV negative tone resist ?**
  - ✓ It is difficult to resolve blight patterning by positive tone resist
  - ✓ For bright patterning, tone inverse (Ex; negative tone resist …) technique would be one of the solution

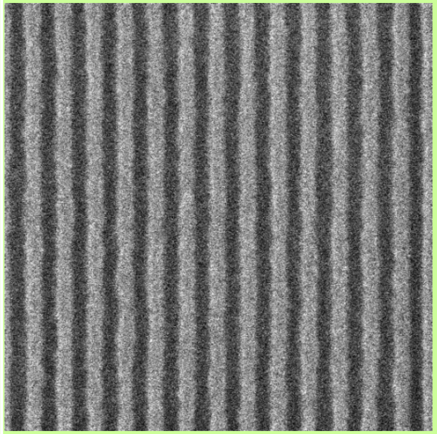
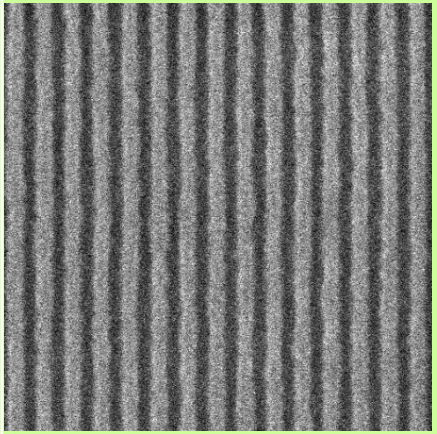
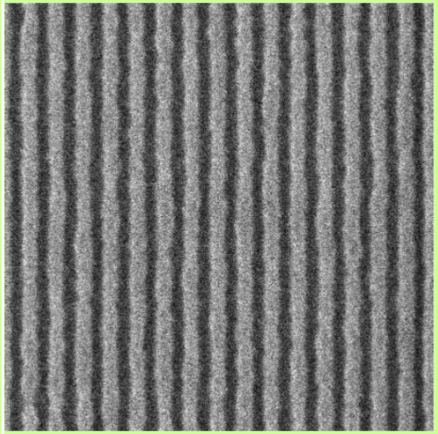
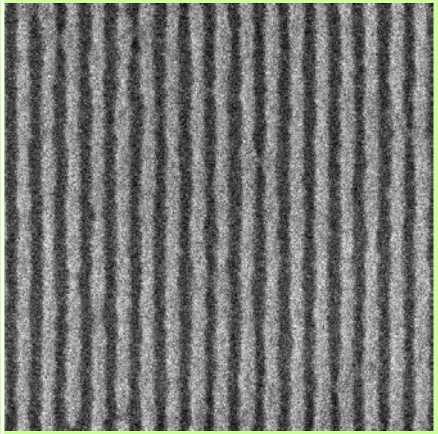
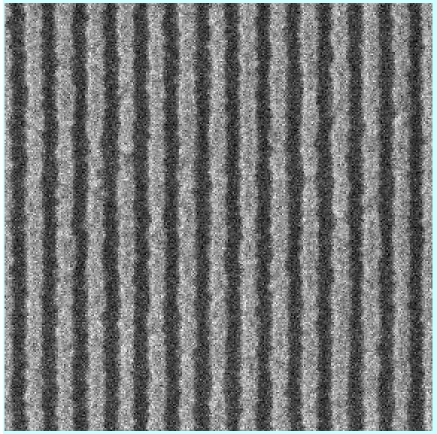
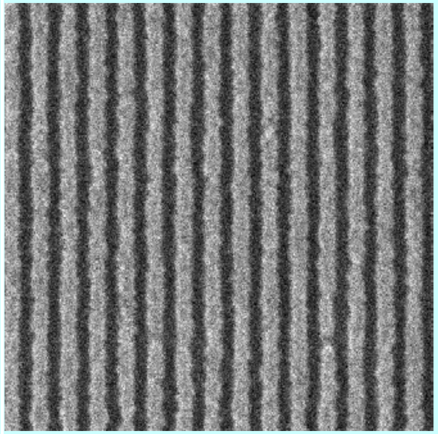
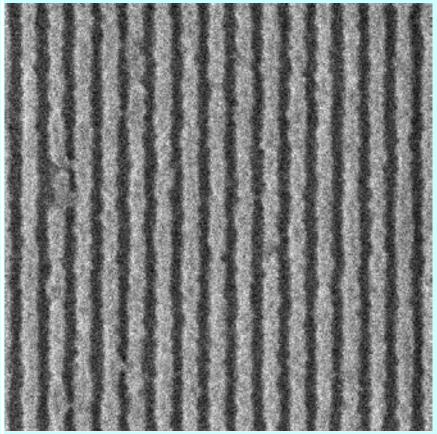
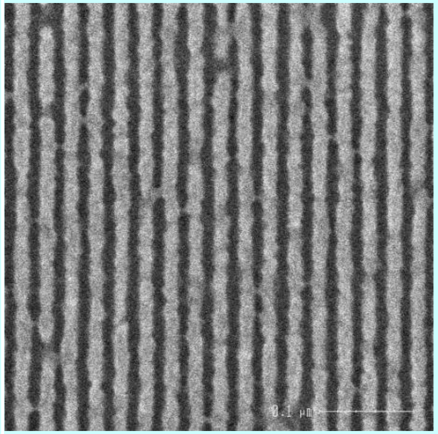
- **Resist design of negative tone with TMAH**

	Positive tone resist	**Negative tone resist**
Exposed area	Acid generation efficiency	
	De-protection efficiency	Crosslinking reaction
Unexposed area	Dissolution rate control	
	Suppression	Enhancement

- Negative tone resist D was designed with positive tone resist concept

NXE3300 Preliminary Result
Negative Tone Resist with TMAH (LS patterning)

Substrate: Organic UL 20nm
Resist FT: 25nm
Illumination: NA 0.33, dipole X45 0.848/0.307
Reticle: Supper NOVA2 metal
Development: TMAH2.38% LD-30s

Sample	16nm hp	15nm hp	14nm hp	13nm hp
Resist B **Positive tone** **DTS:43.0mJ/cm^2** **@14nm hp** **LWR: 5.8nm** **Z-factor: 1.59E-08**				
Resist D **Negative tone** **DTS:27.0mJ/cm^2** **@14nm hp** **LWR: 6.6nm** **Z-factor: 0.94E-08**				

- Negative tone resist showed similar resolution as positive tone with faster sensitivity

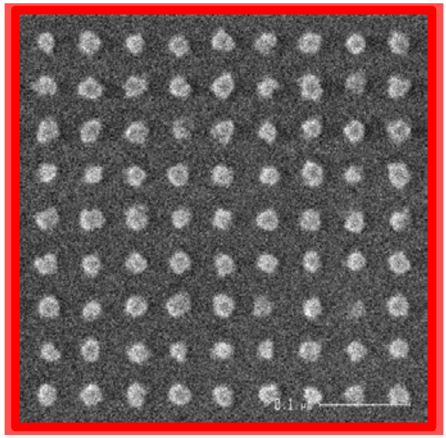
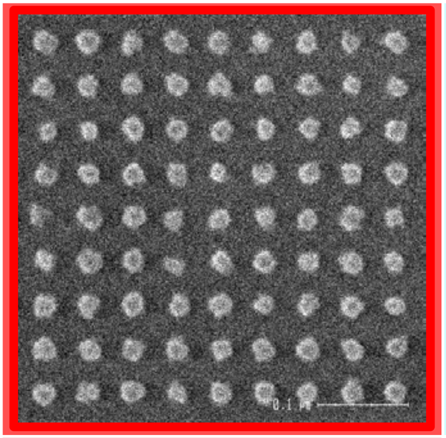
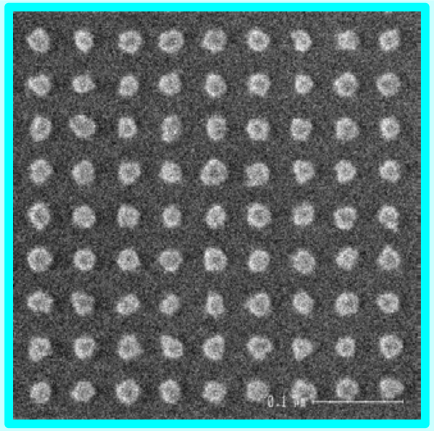
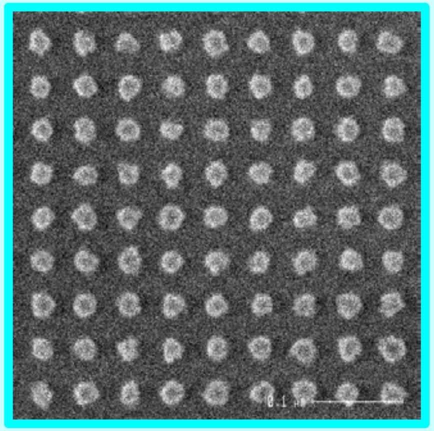
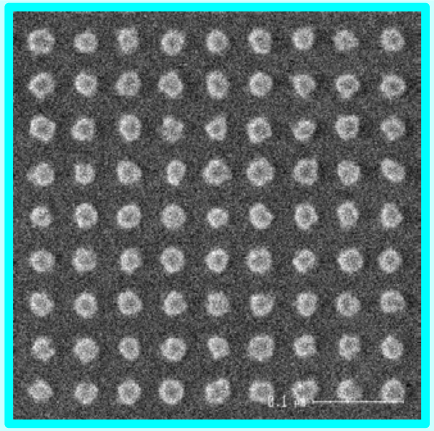
*Z-factor (mJ*nm3)*
$$= (\text{Resolution})^3 \times (\text{LER})^2 \times \text{Sensitivity}$$
T. Wallow et al., Proc. SPIE, 6921, 69211F (2008)

NXE3300 Preliminary Result
Negative Tone Resist with TMAH (Pillar patterning)

Substrate: Organic UL 20nm
Resist FT: 25nm
Illumination: NA 0.33, cquad X45 0.848/0.307
Reticle: EUVOPC5 R02ADF
Development: TMAH2.38% LD-30s

Resist D (Negative tone)

DTS: 35.0mJ/cm^2 @ 24nm hp

33.0mJ/cm^2	34.0mJ/cm^2	35.0mJ/cm^2	36.0mJ/cm^2	37.0mJ/cm^2
				
22.6nm Not resolve	23.8nm Not resolve	24.3nm Resolve	25.4nm Resolve	25.8nm Resolve

- 24nm hp pillar patterning was achieved by negative tone resist

Summary

Development Items of EUV resist

- ✓ Polymer
  - Increasing of proton source unit
  - Increasing of protecting group
  - Applying of new Tg enhancer unit
- ✓ PAG
  - Applying of high quantum yield PAG cation
  - Increasing of PAG amount

TOK Resist Patterning Performance @IMEC NXE3300

Resist	**B**	**C**	**D**	
Tone	**Positive**	**Positive**	**Negative**	
Pattern	**LS**	**LS**	**LS**	**Pillar**
Sensitivity	**41.3mJ/cm^2** **@13nmhp**	**24.0mJ/cm^2** **@16nmhp**	**27.0mJ/cm^2** **@14nmhp**	**35.0mJ/cm^2** **@24nmhp**
LWR	**6.3nm**	**5.4nm**	**6.6nm**	**---**

Acknowledgement

Collaboration Sites

imec

Thank you for your kind attention !!